Applied Mechanics and Materials Vol. 629 (2014) pp 158-163
Online available since 2014/Oct/31 at www.scientific.net

doi:10.4028/www.scientific.net/AMM.629.158

Design and Analysis of an Aircraft Composite Hinge Bracket using Finite Element Approach

Wai Chee Mun[1,a*], Ahmad Rivai[2,b] and Omar Bapokutty[3,c]

[1,2,3] Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya, 76100 Melaka, Malaysia

[a]cmwai@live.com.my, [b]ahmadrivai@utem.edu.my, [c]omarbapokutty@utem.edu.my

Keywords: Composite structure analysis; Composite laminates; Finite Element Analysis.

Abstract. The use of composite materials in aircraft structures have been increasing for the past decade. The anisotropic and heterogeneous nature of composites remains a major challenge to the design and analysis of composite aircraft structures. Composite structures require a different design approach compared to the design of metallic structures. This paper aims to provide a step by step definitive guide to design and analyze composite structures using finite element approach. A simplified design model for the composite structural design was used to analyze an aircraft composite hinge bracket. The composite hinge bracket which is made of IM7/8552 laminated composite plates was successfully designed with a margin of safety of 0.216 and a weight savings of 43.77 percent was estimated.

Introduction

The demand of composite materials in aircraft structures comes from the initiative to reduce fuel consumption in the commercial airlines. Airbus and Boeing has been competing to increase their usage of composite materials in their aircrafts [1]. The increase in composite structures reduces the overall aircraft structural weight which in return reduces the fuel consumption. However, the increase in the demand for composites in aircraft structures can only be seen slightly over the past decade [2]. This increase in demand is brought about by the improvement in manufacturing process and the development in computer capabilities. The huge improvement in the computer speed and memory capacity has enabled Finite Element Analysis (FEA) to be carried out in a much shorter time thus increasing the efficiency and accuracy of the simulation results.

It is the nature of composites to be anisotropic and heterogeneous. Therefore, a different design approach for composite structures is required. The design and analysis of composite structures has always been the major problem. Most of the engineering textbooks [3-7] outline the do's and don'ts in composite design but did not provide a step by step guide to design and analyze composite structures. The industries adopt the guidelines from the textbook to accommodate their design for composite structures, which often involves the use of FEA. Therefore, the objective of this paper is to provide a step by step definitive guide to design and analyze composite structures. A case study to design and analyze an aircraft composite hinge bracket is carried out using finite element (FE) approach, which was simplified from the best practices in the industries [8,9]. This approach is aimed as an introduction to systematic design and analysis of composite structures in the academics.

Literature Study

The academics deal mostly with the study of composite materials. For example, Reddy [4] and Gibson [5] explained on the mechanics, which covers the fundamental theories, of laminated composite plates. These theories are useful to understand the behavior of composites subjected to loads. Some of the textbooks, such as Gurdal et al. [6] and Barbero [7], also provide a guide on the do's and don'ts if composites are to be used to design structures. Textbooks to design aircraft structures, such as those written by Niu [3], allocate a separate chapter which explains on the design of composite structures. However, these textbooks do not explain on the general steps to be taken to successfully design a composite structure such as the Finite Element Method (FEM) model to solve engineering problems or the design model to design machine components. These step to step models are simplified version of detail procedures used in industries to solve engineering problems. They serve as a good introduction to engineering students on how engineering problems are solved in the industries. Various industrial companies, such as Volvo Aero Corporation (VAC), adopted the composite guidelines from the textbooks and incorporate them into their design for composite structures. Aronsson [8] and Karlsson [9] recommended a working method for composite design for VAC after successfully carrying out their research with VAC.

Methodology

The working method for composite design recommended by Aronsson [8] and Karlsson [9] was simplified and used to design a composite hinge bracket for Airbus A320 aircraft spoilers. The simplifications made were based on the limitations of the academics. Fig. 1 shows the proposed composite design model.

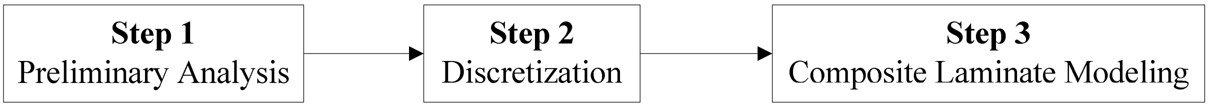


Figure 1: Composite Design Model.

The first step in composite design is to determine the stress distribution of the structure due to different load cases with the assumption that the structure is made out of isotropic homogeneous metallic materials. This step is called the preliminary analysis, which serves the purpose of understanding the behavior of the structure when it is subjected to loads. The use of an isotropic material saves time compared to the time consuming material layup definition of laminated composites. The second step is discretization, which divides the structure into *zones*. These zones are areas of different stress concentration. Since the strength of composite laminate is influenced by the fiber orientation, the zones allow the fibers to be orientation in a way to optimize the strength of the composite laminate. This step is similar to the conceptual design of machine components but instead the concept is applied to material design. Discretization is carried out based on the stress distribution results obtained in the preliminary design.

Step 2 deals with the design of the composite laminates of the different zones of the composite structure while step 3 analyses and evaluates the strength of the laminates by applying the laminate stacking sequence designed in Step 2 to the whole structure. This gives an understanding of the behavior of the structure made of composite when subjected to the load cases identified in Step 1. The analysis of the laminated composite structure is compared with the analysis of the metallic structure. The overall stress distribution of the laminated composite structure should be similar to that of the metallic structure since the stress in a structure is not affected by the type of material. Finally, the overall structural integrity of the laminated composite structure is evaluated by calculation of margin of safety (MS) in each zone based on lamina failure criteria.

Modeling

The hinge bracket is structure which joints the aircraft spoiler to the top surface of the aircraft wings. The hinge allows the upward and downward movement of the aircraft spoilers. One of the brackets is attached to the spoiler while the other is attached to the wing. Therefore, fixed constraints are applied on the bolt holes while loads are applied to the lug of the hinge bracket. Fig. 2 shows the Computer Aided Design (CAD) drawing of the hinge bracket. The hinge bracket design and loads are provided by Spirit Aerosystem.

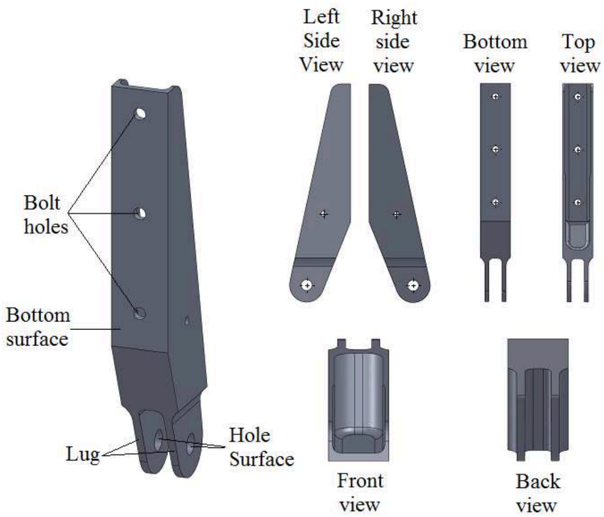


Figure 2: CAD Model of A320 Hinge Bracket

A three dimensional (3D) finite element (FE) model was used in the preliminary analysis of metallic hinge bracket. A 3D FE model was used since it is able to illustrate the stresses and deformation of the hinge bracket in all three axes, which are x-axis, y-axis, and z-axis. A two dimensional (2D) FE model was used in the composite laminate modeling of the laminated composite hinge bracket. Since the hinge bracket has a shell like structure, it would be easier to model it in 2D yet obtain similar FEA results as that of a 3D model. The material properties used for the metallic hinge bracket are listed in Table 1. The lamina properties of IM7/8552, listed in Table 2, were calculated using micromechanics formula recommended by Barbero [7] with the fiber and matrix properties obtained from Hexcel [10,11].

Table 1: Mechanical Properties of AA7075-T651

Elastic Modulus (MPa)	71700
Ultimate Tensile Strength (MPa)	572
Yield Strength (MPa)	503
Poisson’s Ratio	0.33
Density (g/cm^3)	2.81

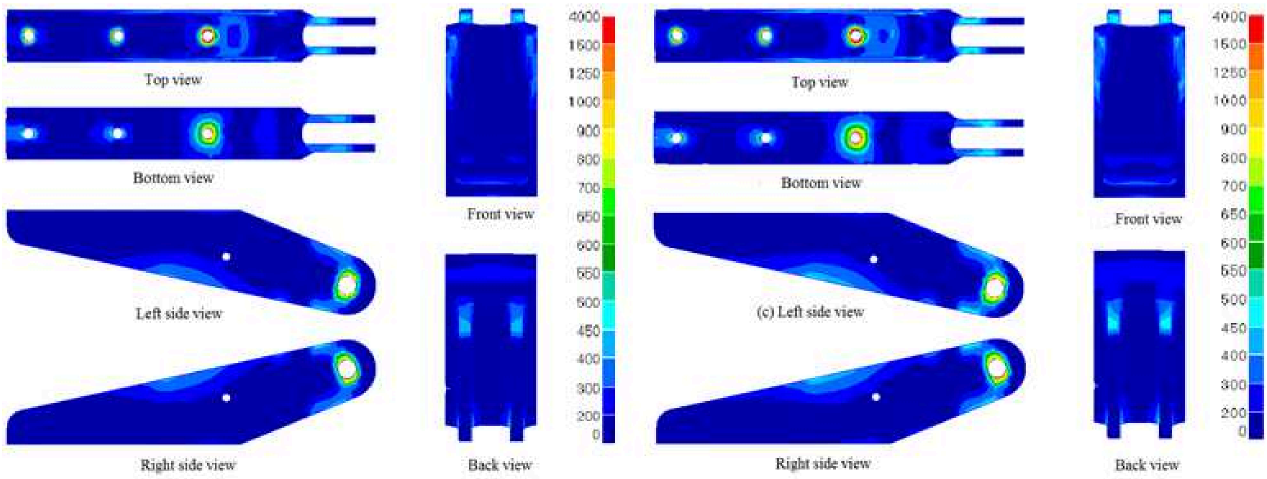
Table 2: Mechanical Properties of IM7/8552 Lamina

Longitudinal Modulus (MPa)	167480
Transverse Modulus (MPa)	23437
In-plane Poisson’s Ratio	0.34
In-plane Shear Modulus (MPa)	5574
Longitudinal Tensile Strength (MPa)	3441
Longitudinal Compressive Strength (MPa)	5574
Transverse Tensile Strength (MPa)	100
Transverse Compressive Strength (MPa)	288
In-plane Shear Strength (MPa)	121
Density (g/cm^3)	1.588

Results and Analysis

Preliminary Analysis. The function of aircraft spoiler hinge is to enable the upward and downward movement of the aircraft spoiler. The spoiler will either open or close when necessary. The wing of an aircraft in ideal case is assumed to be rigid. However, in actual case, there could be wing bending. The wing may bend upward or downward. An upward wing bending is assumed to be positive wing bending while a downward wing bending is assumed to be negative wing bending. Therefore, the effect of wing bending must be considered for both cases of spoiler close and open.

Linear elastic static analysis was carried out on the 3D FE model of the metallic hinge bracket using two different FE softwares, which are MD Nastran and Abaqus CAE. Stresses are obtained from different location of the hinge bracket. Table 3 shows the Von Mises stresses obtained at the bolt and lug holes of the hinge bracket.



(a) (b)

Figure 3: Stress Distribution of Metallic Hinge Bracket: (a) Spoiler Close; (b) Spoiler Open

Table 3: Comparison of Stresses at the Bolt and Lug Holes of the Hinge Bracket

Case		Von Mises Stresses			
		Bolt		Lug	
		Nastran	Abaqus	Nastran	Abaqus
Spoiler close	No wing bending	1888.67	1890.59	842.083	841.171
	+ve wing bending	1751.50	1752.65	839.882	838.970
	-ve wing bending	1997.80	2000.37	843.971	843.058
Spoiler open	No wing bending	2117.22	2120.62	908.117	907.134
	+ve wing bending	2286.98	2272.59	910.938	905.301
	-ve wing bending	2008.14	2010.88	906.231	905.248

It is found that the wing bending only affects the magnitude of the stresses. The worst case when the spoiler is close is when there is a negative wing bending while the worst case when the spoiler is open is when there is a positive wing bending. The difference in the stress values obtained between MD Nastran and Abaqus CAE is also very small. Hence, the FEA results are considered valid. FEA results yield should be similar regardless of the FE software used as long as the problem statement, which consists of the loads and boundary conditions, mesh quality, and material properties, is modeled correctly.

Discretization. The hinge bracket was divided into different zones based on the stress distribution obtained in the preliminary analysis step. Fig. 4 shows the discretized zones of the hinge bracket. Each zone is given a different laminate stacking sequence based on the Classical Laminate Theory (CLT) for thin plates. Table 4 shows the laminate stacking sequence of each zone of the composite hinge bracket.

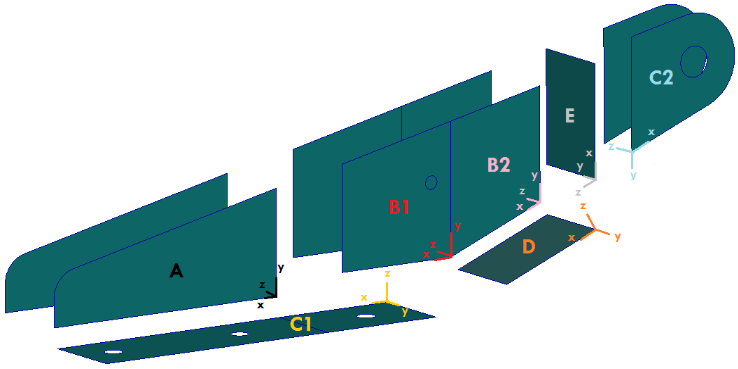


Figure 4: Discretization of 2D FE Model of A320 Hinge Bracket

Table 4: Composite Laminate Layup for Each Zone of A320 Composite Hinge Bracket

Zones	Laminate Thickness (mm)	No. of Plies	Stacking Sequence
A	2	16	$[0_2/(\pm15)_3]s$
B1	3	24	$[(\pm15)_4/0_8/\pm15/-15_6]_T$
B2	3	24	$[0_4/(\pm15)_4]s$
C1	4	32	$[(\pm45)_2/(90/0)_2/(0/\pm45)_2/0_2]s$
C2	4	32	$[(\pm15)_2/(0/\pm15/0)_2/0_4]s$
D	2.5	20	$[0_{20}]$
E	8.5	68	$[(\pm45)_5/(0/\pm45)_4/(90/\pm45/0)_3]s$

Composite Laminate Modeling. The failure analysis of the 2D FE model of the composite hinge bracket with laminate stacking sequence as listed in Table 4 yields positive results for the overall MS. The worst case of MS for each zone of the composite hinge bracket is listed in Table 5. It can be seen that all the zones except Zones C1 and C2 yields a positive MS. The negative value of MS is due to the stress concentration at the bolt and lug holes. This phenomenon is justified by the Saint Venant's principle and can be neglected. A 3D assembly analysis is required to evaluate the stresses at the holes. The worst MS is, therefore, occurs at Zone E when the spoiler is open with a value of 0.216. Compared to the metallic hinge bracket, the composite hinge bracket shows a savings in weight up to 43.77 percent. The weight savings is calculated using the difference in the material density.

Table 5: Summary of Worst MS for Each Zone of the Composite Hinge Bracket.

Zone	MS	
	Spoiler Close	Spoiler Open
A	1.54	0.648
B1	0.597	0.705
B2	0.787	0.620
C1	-0.780	-0.780
C2	-0.836	-0.849
D	1.91	1.16
E	0.451	0.216

Summary

A composite hinge bracket, made of IM7/8552 laminated composite plates, for the Airbus A320 aircraft spoilers has been successfully designed with a margin of safety of 0.216 and weight savings of 43.77 percent. The design of the composite hinge bracket was carried out using a simplified composite design model. The composite design model is a simple three steps, which are preliminary analysis, discretization, and composite laminate modeling, model with definitive purpose, requirements and outcome in each step. It is a systematic but iterative approach which improves the confidence level by identifying the stress distribution of different areas of the structure when designing laminate composite structures. Since the strength of laminated composite structures are determined by the macromechanics such as the laminate stacking sequence, identification of the stress distribution allows the optimization of the macromechanics factors to be performed on the composite structure. The success of this composite hinge bracket proves that the composite design model can indeed be used to design composite structures. The simplified composite design model is proposed as a definitive step by step guide to design and analyze composite structures in the academics. It is hoped that this composite design model is able to benefit academicians in their research and development of composite materials and structures.

Acknowledgement

The authors would like to acknowledge CRIM, and Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka (UTeM) for supporting the present work through PJP/2012/FKM(18C)S1112 Research Fund.

References

[1] A.R. Bunsell and J. Benard, Fundamentals of fibre reinforced composite materials, IOP Publishing Ltd, London, 2005.

[2] C. Soutis, Carbon fiber reinforced plastics in aircraft construction, Materials Science and Engineering A, 412 (2005) 171–176.

[3] M.C.Y. Niu, Composite airframe structures, 3rd ed., Conmilit Press Ltd., Hong Kong, 2010.

[4] J.N. Reddy, Mechanics of laminated composite plates and shells: Theory and analysis, CRC Press, Boca Raton, 2004.

[5] R.F. Gibson, Principles of composite material mechanics, 3rd ed., Taylor & Francis Group, Boca Raton, 2012.

[6] Z. Gurdal, R.T. Haftka, P. Hajela, Design and optimization of laminated composite materials, John Wiley & Sons, United States of America, 1999.

[7] E.J. Barbero, Introduction to composite materials design, 2nd ed., Taylor and Francis Group, United States of America, 2011.

[8] A. Aronsson, Design, modelling and drafting of composite structures, Master of Science Thesis, Lulea University of Technology, 2005.

[9] H. Karlsson, Evaluation of FE-software for mechanical analysis of composite materials, Master of Science Thesis, Lulea University of Technology, 2005.

[10] Hexcel, 2013. HexPly 8552 Epoxy Matrix (180°c/356°F curing matrix) Product Data. [Online] Available at: http://www.hexcel.com/Resources/DataSheets/Prepreg-Data-Sheets/8552_eu.pdf.

[11] Hexcel, 2013. HexPly 8552 Epoxy Matrix Mid-Toughened, High Strength, Damage-Resistant, Structural Epoxy Matrix Product Data. [online] Available at: http://www.hexcel.com/Resources/DataSheets/Prepreg-Data-Sheets/8552_us.pdf.

AEROTECH V: Progressive Aerospace Research
10.4028/www.scientific.net/AMM.629

Design and Analysis of an Aircraft Composite Hinge Bracket Using Finite Element Approach
10.4028/www.scientific.net/AMM.629.158